TELESCOPES FOR STELLAR PHOTOGRAPHY.[1]

I.

I WILL ask you to remember that the subject of this paper is not that of the proposed international photographic survey of the heavens itself, but of the instruments which are to be used for that survey. No doubt a communication on the survey itself, dealing with the results aimed at, the conditions under which it is considered the best results may be arrived at, and the general scheme under which it is proposed to measure, define, and catalogue the position of the stars obtained, would be more generally interesting than one on the mere instrumental equipment; but this part of the subject has already been amply and most efficiently dealt with in lectures by Mr. Common and Dr. Gill at the Royal Institution, while the subject of the instruments to be used has only as yet been discussed in the more scientific and technical journals or proceedings of Societies; besides which, I may be pardoned for saying that I think when actual work is commenced, the perfection of the instrumental equipment will be found to be a larger factor in the attainment of success than has ever been the case in any previous astronomical research. There is probably nothing which surprises and excites the admiration of the modern astronomer more than the work done in bygone times by some of the older astronomers—work which was the outcome of marvellous patience and ingenuity while working with tools which would excite the pity and contempt of the merest tyro in astronomy of the present day; but while I am by no means a sceptic as to the most important part of all telescopes being "the man at the small end," I do believe that never before in any system of astronomical observing has "the man at the small end" been so completely dependent on the excellence of his instrumental equipment, a disarrangement of any one part of which would leave him utterly helpless. I trust, therefore, you will bear with me while discussing and describing a few of the more important mechanical details of these instruments.

You are aware, probably, that an International Congress of Astronomers was held last year in Paris, and that it was decided to start a number of Observatories, in various parts of the world, each to take its share in producing photographs of the heavens, to be afterwards used in compiling a general chart, in which stars down to the 14th magnitude would be entered.

Before we go further, it may be well to explain the difference between this system of charting and the old system, and what circumstances have led to this proposed revolution in astronomical work.

The system of mapping stars which has been used up to the present time consists, as you are aware, in observing all the stars *seriatim*, in a transit circle, or similar instrument, and tabulating their declination (*i.e.* angular distance north and south of the equator), or Polar distance, as found by readings of the vertical centre, and their right ascension (*i.e.* their distance measured on the equator from an empirically fixed point in the heavens), as found by the difference of time of the sidereal clock between the passage of the star across the centre wire of the telescope and that of the fixed point above referred to. The essential point in the above system which I have to direct your attention to is, that every single star has to be examined *by itself*.

The magnitude of the work of such a survey as the Paris Congress has decided upon may be inferred from the fact that there are probably some 20,000,000 stars to be examined and catalogued. It is a good year's work of a transit circle to tabulate 5000 stars; supposing, therefore, thirty or forty Observatories divide the work between them, the survey would still occupy over 100 years, and by that time the proper motion of the stars would render a new survey necessary.

Now, ever since photography has been practised, it has been the dream of the astronomer to photograph the heavens, and obtain, at one and the same time, the positions not of one but of hundreds, or perhaps thousands, of stars in each operation. But then, it may be asked, why was not photography employed long since? The answer is, that until recently the amount of sensitiveness obtained was not sufficient to allow of the fainter stars impressing the plate within reasonable time, and consequently it was found impossible to produce satisfactory stellar photographs, except of the larger stars.

Dr. Warren De la Rue was the first to point out the use which might be made of photography for the purpose of star-charting, and, as far back as 1860 and 1861, produced photographs of star-clusters, &c.

In 1864 or 1865, Rutherford, of New York, obtained photographs of the larger stars, and while photographing the moon with the great Melbourne telescope in 1867 I took, for the purpose of adjustment, some photographs of "Castor"; but in an article which I wrote for the "British Journal Photographic Almanack" in 1869, I pointed out that for the development of celestial photographs we would have to look to the chemist and not to the optician—in other words, that until we obtained more suitable plates we could not expect much advance. This has proved to be the fact, for with the advent of the gelatine plates, and consequent increase of sensitiveness, celestial photography received that impetus which has eventuated in this proposition of an international photographic survey. I also pointed out in that same article nineteen years ago that if by any possibility the exposures could be reduced so far as to render the unsteadiness of the image insensible—a rapidity which I said there was no reason to suppose might not be obtained in the case of the sun—we might expect great results, a prediction which has since been verified by Prof. Jansen's magnificent pictures of the sun, with which you are all familiar.

It is almost superfluous to remind you also of the magnificent picture of the nebula in Orion by Mr. Common, an example of celestial photography never yet surpassed.

In 1882, Dr. Gill sent home to the Royal Astronomical Society, and to the Paris Academy of Sciences, a photograph of the great comet of that year, and called attention to the large number of stars photographed on the same plate. This photograph was obtained with an ordinary photographic lens and camera attached to a clock-driven equatorial.

It was this, perhaps, that influenced the Paris Observatory to construct the photographic telescope of about 13 inches aperture, 11 feet focal length, specially corrected for the chemical rays, with which the splendid star charts of the Messrs. Henry were obtained. Meanwhile, others were not idle, and while Dr. Gill, through the munificence of Mr. Nasmyth, obtained a 9-inch achromatic, which I corrected of course for the chemical rays, Mr. Roberts, of Liverpool, had a 20-inch reflecting telescope constructed for the same purpose.

It soon became evident that this new departure in the system of star-charting was likely to be of very great importance, and consequently an International Congress of Astronomers assembled last year in Paris to discuss the whole question. This Congress defined the size and focus of the object glasses to be used, and laid down a certain standard for the correction of the chromatic aberration suitable to the nature of the work; but left almost all other points free for individual astronomers to deal with as they thought best. In fact, the Congress wisely defined only just such points as were necessary for securing uniformity in the scale of the photographs, all of which it is proposed shall be sent to some central bureau to be examined, discussed, and made use of in compiling the chart.

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[1] A Paper read by Sir Howard Grubb, F.R.S., before the Society of Arts, on April 18, 1888.

But it may be asked where is the great difference between this system and the old, as the positions of the star images on these photographs have to be measured *seriatim*, just as the stars themselves have to be measured *seriatim* in the old system. This is no doubt true, but under what different conditions are the measurements made.

None but those who have worked in this field know the labour represented by a volume of 5000 star places under the old system.

How many times does that wretched bit of cloud come across the field just as the star reaches the centre wire of the micrometer, and how many nights, beautiful and clear as they may look to ordinary individuals, prove utterly worthless for observing purposes; but under the new system, once a single good plate has been obtained, there is a permanent record of some hundreds, or in some cases thousands, of stars, which can be measured at leisure by day or by night, in good weather or bad weather, and in comfort in your office or study, and there also is that photograph as a permanent record which can be referred to at any time as a check on errors which might possibly creep in to some of the final reductions.

In fact, this new system gives us the means of taking advantage of the very few really favourable opportunities of observing, and of producing, during those favourable moments, a *facsimile*, so to speak, of any portion of the heavens which we can examine and survey at our leisure without any of the difficulties or discomforts attendant upon direct astronomical observations, and under conditions far more favourable to the obtaining of accuracy in the results.

Let us now consider what are the chief points to be attended to in the construction of the instrument. It is evident that what is required is an instrument which—

(1) Can be accurately pointed at any given object.

(2) That when pointed in the desired direction the clockwork shall cause it to follow that object as steadily as possible.

(3) That as the meridian is the best position for observation, the instrument should be capable of working for some distance on each side of the meridian without reversing.

(4) That means should be supplied by which the observer can watch and verify the accuracy of the clock-driving, or making any change in position rendered necessary by refraction.

The first point involves delicate and accurate slow motions in right ascension and declination.

The second involves great steadiness and rigidity of the mounting, great smoothness of motion of the polar axis in its bearings, and above all most accurate clock-driving motion.

The third point involves either the adoption of the old English form of mounting, or a modification of the German form, as the latter does not generally allow of motion for any considerable extent beyond the meridian without reversal.

The fourth merely involves a very powerful finder—or, rather, guiding—telescope with suitable micrometric eye-piece arrangements.

Respecting the relative merits of refractors and reflectors for this purpose, I shall speak just now; for the present I wish to direct your attention to the instrumental part only, and, for the better understanding the peculiarities of the various mountings, I will now throw photographs of some of them on the screen.

The first illustration is that of the Paris equatorial, with which the well-known and deservedly praised star pictures of the Messrs. Henry were produced. You see it is of the construction generally known as the "English" equatorial,—a long split polar axis, with bearings for carrying the telescope at the centre (its weakest point). This form of equatorial has many advantages, which at first seem to render it peculiarly fit for this special work. With good slow motion, and a large finder telescope, it admirably fulfils the first, third, and fourth of the above conditions; but, owing to its peculiar form, and the difficulty of using a driving sector of long radius, it is not well calculated to fulfil the second and most important of all conditions, viz. the accurate following. No doubt excellent work has been done with it by what is called the "eye and hand" guiding. That is, the star is watched in a powerful finder, and when it is seen to err sensibly in position, it is brought right again by the slow motion handle. I think it is generally allowed that the undoubted excellence of the work done by the Messrs. Henry is due more to extraordinary patience and skill in the "eye and hand" guiding than to any unusual perfection of the clock-driving. This form of instrument also possesses a disadvantage in being very difficult to arrange for work near the Pole.

The second illustration is of Dr. Gill's 9-inch photo telescope, with which he took his star pictures. There is nothing peculiar about the mounting of this, being in fact an old equatorial which I sent him some years since. In this case also the excellence of his results is to be attributed to the skill of the observer, and not to any inherent excellence of the clockwork; but that excellent work has been done with it is apparent from the perfection of some of his photographs.

The next illustration is that of the telescope of Mr. Isaac Roberts, of Liverpool, for whom I mounted a 20-inch reflector to experiment with. As you see, it is mounted on what I call the twin form, as I mounted Dr. Huggins's instrument, by the adoption of which the observer always has a second telescope available for visual work, if anything interesting should appear in the heavens. With this instrument Mr. Roberts, working in the exceptionally wretched atmosphere of Liverpool, has secured some most admirable work, a few specimens of which I now throw on the screen.

This is the first instrument, as far as I know, in which a successful attempt has been made to drive, for any considerable time, without "eye and hand guiding." The special system of clockwork used I will describe further on. So far as the general form of the instrument is concerned, it would appear that the balance of advantage lies with the German form (so called) — that usually adopted in this country. It is capable of being made of great stability, and it admirably fulfils all the conditions except the third, but that also, by a little modification, can be managed.

The next illustration shows the general form which I have adopted, the principal feature of which is great stability. The stand being cast all in one piece contributes to this, but the peculiarity of the system of equipoise probably has more to do with it. In designing these instruments, I proposed that the fulcrum of the levers which support the greater part of the weight of the polar axis, should be attached, not to the frame of the instrument, but to an independent pillar, so that only a very small portion of the weight of the moving parts should be carried by the main framing. Dr. Gill then proposed that I should also allow the levers to act in a purely vertical direction, instead of, as usual, in a direction at right angles to the polar axis, and to let the point of support be vertically under the centre of gravity of the whole moving part. This I have carried out, and the result is that only as much of the weight of the whole instrument as is necessary to insure steadiness will rest on the bearings (lateral or end bearings) of the polar axis; all the rest is transferred to the base of the stand.

We now come to consider the all-important part of the photographic equatorial—that is, the driving clock.

All clocks used for driving equatorials (which must of course move uniformly, and not step by step as pendulum clocks), may be divided into two classes—(*a*) those in which uniform motion is obtained, or sought to be obtained, by some variable friction or resistance which increases as the speed increases; and (*b*) those in which some such similar contrivance is supplemented by a system of electric control from a pendulum clock, which is itself incapable of being re-acted upon by the uniform motion clock.

For all ordinary observing, and even for micrometric work, clocks of the class *a* are made, which answer admirably, but for photographic equatorials I believe it will be found necessary to employ clocks of the *b* type, and for this reason: the tendency of the compensation in uncontrolled clocks (class *a*) is to correct the *rate* of the clock when from any momentary cause it is disturbed. The best it can do is to bring the *rate* absolutely right again, but it cannot act till an error has actually occurred, and therefore, although the rate is corrected, the *position* of the star on the plate is shifted by the amount of the error. I have heard it stated by the designers of some of these clocks that errors were corrected *before* they existed! It is hardly necessary to stop to show the fallacy of this, but it is evident that the increased or diminished resistance, or friction, or whatever it is, that checks the speed, can only exist from, and in consequence of, the error itself.

In the case of micrometric measures, it is not of very much consequence if a minute error occasionally creeps in, provided the speed keeps constant during the few seconds or minutes required for making the bisections, but in the case of the photographic telescopes, if the image of the star takes up a new position any time during the exposure, it is of course fatal.

Let us try now and get an idea of what amount of accuracy is really necessary for this work. We often hear of a perfect equatorial clock, but the word perfect is, I fear, as loosely used in this connection as in others.

I have heard in days gone by a perfect clock defined as one which drove the instrument so accurately that if you set the telescope on a star and went to dinner you would find the star still in the field when you resumed your observations after dinner. Allowing, say, two hours between the ante-prandial and the post-prandial observations, and assuming the eye-piece to be (as we may fairly do) a low one of about 20′ of arc field, this would mean that the clock did not vary more than 600″ of arc or 40 seconds of time an hour. The accuracy we now require for these photographic telescopes is something very different. The image of a 12th magnitude star impresses itself on the plate, with moderate exposure, in the form of a circular disk of about $\frac{1}{700}$ inch diameter. If the clock vary one-tenth of a second during the exposure, the disk will be elongated by $\frac{1}{1000}$ inch, producing a very sensible distortion.

We must not therefore have any errors over one-tenth of a second, and if possible it should be reduced to one-twentieth.

It will not be necessary that the clock keep within this one-twentieth of a second for more than ten or fifteen minutes, because it is always necessary to watch the image occasionally through the guiding telescope, and correct whenever refraction becomes apparent; but what I do urge as absolutely necessary is that the clock shall go so perfectly as not to require more than the occasional attention of the observer, instead of the constant and never-ceasing watching with ordinary clockwork. No one who has not tried it can imagine the strain required to keep a constant watch on a star image for 30 or 40 minutes, but if attention be only required for a second or so every few minutes there is no difficulty or irksomeness whatever.

Even the most enthusiastic admirers of various forms of equatorial clocks will not venture to assert that they will go for fifteen minutes without one-tenth of a second of error. There is now, however, no difficulty in controlling a uniform motion clock from a pendulum so that it will never vary one-twentieth of a second from it. It may therefore, I think, be assumed that some form of electrical control is necessary. There are, as far as I know, four forms of control to choose from.

First, Dr. Gill's, as applied to the 15-inch equatorial at Dun Echt with admirable success.

In this an electric current is sent once a second from an independent pendulum, which may be any distance away. That current passes through a certain wheel in the clock, with contacts so arranged that if the clock be going exactly with the pendulum the current is sent in a direction which keeps one of two rubbers rubbing on a quick-moving wheel of the clock. If the clock, however, goes the least quantity too fast, the wheel has revolved a little further than it should at the moment the next current comes from the pendulum, and the current is sent in such a direction as to cause both rubbers to rub on the clock wheel. If, on the contrary, the clock has gone a shade slower, the current is sent in a third direction, which lifts both rubbers off. This control, so far as it goes, acts almost perfectly, but it is open to this objection, that as it only corrects the errors of whatever shaft in the clock the contact-wheel is attached to, any error in wheels between that and the telescope screw are unaffected by it; also I find in practice that when it is attempted to control a clock by alteration of friction, on any heavy quick-moving part, it takes some little time to act, and then generally overdoes the correction, causing what is generally termed "hunting." The second form of control is the first which I introduced.

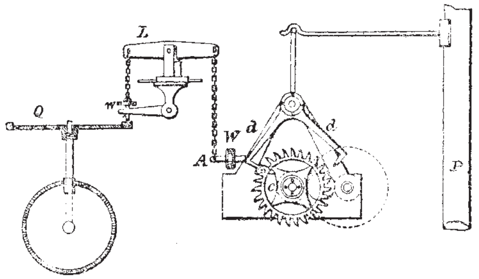

FIG. 1.

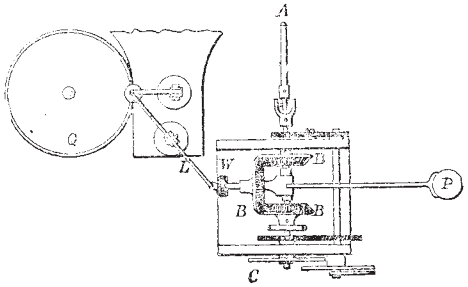

FIG. 2.

Fig. 1 is an elevation, and Fig. 2 a plan, of the arrangement which is attached to the back of the main clockwork, and can be seen in Fig. 3 at E, but on too small a scale for description; A is a portion of one of the uniform clock motion spindles, or any shaft coupled thereto; B, B, B, are the three wheels of an ordinary mitre *remontoire* train driving by weights, W, the scape-wheel, C, into the teeth of which gear the pallets, D D, which pallets are driven by the electric pendulum, P.

The electric pendulum is connected to and driven by a current from any independent clock. To the weight-carrying arm of the *remontoire* is attached a small chain or wire, which communicates any motion it may have to the lever, L, from the other end of which lever hangs a weight, *w*, smaller than W, which weight is therefore raised when the *remontoire* arm is lowered, and lowered when the *remontoire* arm is raised; Q is a disk of metal on a vertical spindle of a uniform motion clock, and revolving rapidly (say 300 per minute). When the weight, W, is below its mean position, it is in contact with the disk Q, and (the lower end of it being coated with leather) produces a considerable amount of friction, and therefore tends to retard the speed of the clock; when the weight, W, is above its mean position, it is altogether out of contact with the disk Q. The action is as follows: Supposing the shaft, A, to be revolving exactly one per minute, the pendulum to be vibrating exactly 60 per minute, and that there are 30 teeth in the scape-wheel, it is evident that the *remontoire* arm, and therefore, the weights, W and *w*, will vibrate backwards and forwards the same distance each second, and that the mean position of all will be the same each second. Under these circumstances, the weight, W, will be alternately 0·5 second in contact with the disk Q, and 0·5 second out of contact, and the uniform motion clock is rated, *per se*, just so much fast, that the resting of the weight, W, for 0·5 second in each second, will bring the rate right.

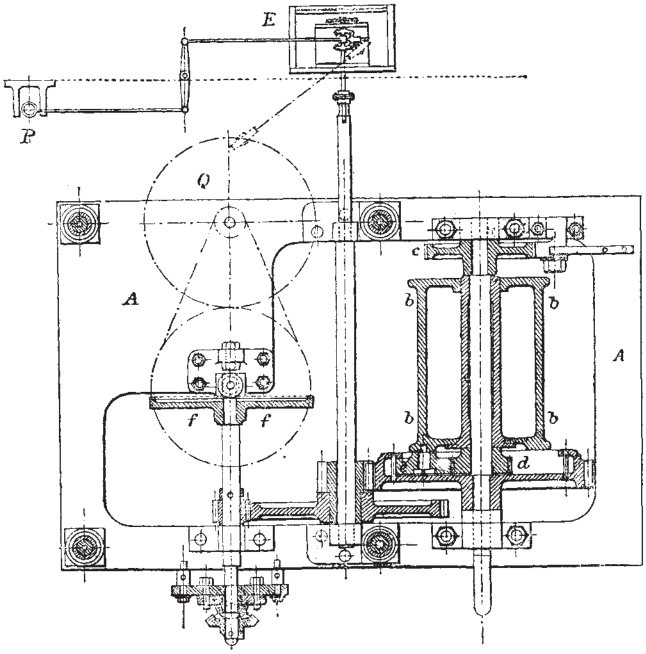

FIG. 3.

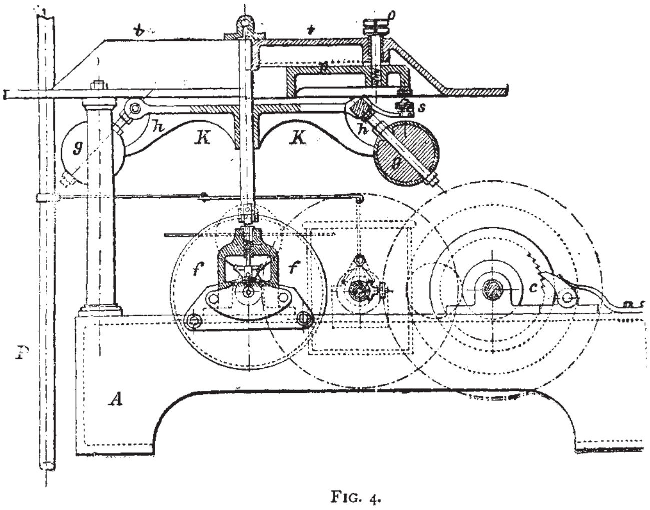

FIG. 4.

Now, suppose an error of acceleration to arise in the uniform motion clock, the mean position of *remontoire* arm will rise; therefore W will fall, and, instead of rubbing in contact with Q for 0·5 second, it will rub for 0·6 or 0·7 second, according to the extent of the error. This will tend to check the rate, and this check will continue till the relative position of the uniform motion shaft becomes as it was when the clock was going correctly.

If a retardation occurs, the reverse effect will take place, and the weight, W, will rub only for 0·4 or 0·3 second, instead of 0·5, until the error be corrected.

So far as described, there was no particular novelty, as most of this arrangement, in principle, had been tried before, the failure that had resulted being due to the fact that it was found impossible to prevent the pendulum being influenced by the difference of force on the pallets, under varying circumstances, the pendulum being in the former case driven by the scapement; not by electricity, as in this case.

This difficulty was got rid of by:—

(1) Making the pallets (as they are not required to drive the pendulum) of such form that the teeth of the scape-wheel impinge upon them nearly at the angle of repose.

(2) By driving the pendulum by electric current from another clock, thus virtually rendering the pendulum not a pendulum at all, but a lever worked backward and forward by electricity, and not subject to alteration in its rate by slightly varying force on the pallets.

An arrangement is also attached (but not shown in the figure, to avoid confusion) by which, if either portion of the clock fails to do its duty from want of winding, want of electric current, or other cause, the connection between the two systems is instantly severed, automatically.

(*To be continued.*)

NOTES.

MR. GRIESBACH, of the Geological Survey of India, who has lately been engaged in geological work in Afghanistan, and who was geologist to the Afghan Boundary Commission, has been appointed to Beloochistan, "to carry on geological investigations into the mineral deposits of the country."

AT the meeting of the British Association at Newcastle there will be a joint discussion by Sections B and G of a paper to be read in the latter Section by Sir I. Lowthian Bell, F.R.S., President of Section B, on "Blast Furnace Practice."

THE International Astronomical Congress will hold its sittings in Brussels from the 10th to the 12th inst., and at Liége on the 13th. The attendance from all European countries and America will, it is anticipated, be very large.

IT is reported from Brussels that M. Dutoit, the Transvaal Minister of Public Instruction, is now endeavouring in Belgium and Holland to recruit the necessary staff for organizing a Dutch University in Pretoria, the capital of the Transvaal.

COLONEL THUILLIER'S report on the progress of the Survey of India for the past year shows that the party employed on the trigonometrical surveys has completed the 370 miles remaining of the secondary triangulation along the east coast of India. The secondary triangulation was also carried out for an aggregate